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SPRAYS PRODUCED BY PRESSURE AND AIR
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**EFFECT OF AIRSTREAM VELOCITY ON MEAN DROP
DIAMETERS OF WATER SPRAYS PRODUCED BY
PRESSURE AND AIR ATOMIZING NOZZLES**

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SPRAYS PRODUCED BY PRESSURE AND AIR ATOMIZING NOZZLES

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ABSTRACT

A scanning radiometer was used to determine the effect of airstream velocity on the mean drop diameter of water sprays produced by pressure atomizing and air atomizing fuel nozzles used in previous combustion studies. Increasing airstream velocity from 23 to 53.4 meters per second reduced the Sauter mean diameter by approximately 50 percent with both types of fuel nozzles. The use of a sonic cup attached to the tip of an air assist nozzle reduced the Sauter mean diameter by approximately 40 percent. Test conditions included airstream velocities of 23 to 53.4 meters per second at 293 K and atmospheric pressure.

INTRODUCTION

Experimental tests were conducted with pressure-atomizing and air atomizing fuel nozzles mounted in a duct 5 meters in length and 15.3 centimeters in diameter. Water was used to simulate fuel in this investigation of the effect of airstream velocity on the fineness of atomization. A scanning radiometer that measured the forward scattered light was used to determine the Sauter mean diameter at each test condition. Although water was used in all of the tests, the results may be compared with atomization of fuels such as Jet A by correcting for the effects of fuel density, surface tension, and viscosity on atomization as given in reference 1.

Fineness of atomization is an important factor in the design and performance of fuel injectors that will yield high combustion efficiency and low exhaust emissions when used in advanced turbojet combustors. In references 2 and 3, it was found that air atomizing fuel nozzles improved combustor performance and reduced exhaust emissions when compared with pressure atomizing nozzles. This result was attributed to improved atomization and dispersion of the fuel. However, instrumentation was not available to actually determine the degree of fineness of atomization of the various sprays. Thus, the present study was made to determine the effect of airstream velocity on the Sauter mean diameter produced by pressure-atomizing and air atomizing fuel nozzles. Such data are needed to relate fineness of atomization to combustor performance and exhaust emissions.

In the present investigation, pressure atomizing and air atomizing nozzles used in previous combustion studies were tested over an airstream velocity range of 23 to 53.4 meters per second at 298 K and atmospheric pressure. Sauter mean diameters were measured with the scanning radiometer, and the effect of airstream velocity on the Sauter mean diameter was

determined. A comparison was also made of the Sauter mean diameters obtained with a conventional and a sonic air assist nozzle.

APPARATUS AND PROCEDURE

The scanning radiometer was mounted near the end of the open duct test facility as shown in figure 1. Air drawn from the laboratory supply system was at ambient temperature and pressure in the test section, i.e., 298 K and 1.01×10^5 newtons per square meter, respectively. The airstream velocity was controlled with the valve directly downstream of the air orifice. The test section, also shown in figure 1, was a 15.24-centimeter inside diameter duct having a length of 5 meters. The tip of each test injector was located at a distance of 16.5 centimeters upstream of the center line of the 7.5-centimeter-diameter laser light field.

DESCRIPTION OF INSTRUMENT

The scanning radiometer, shown in figure 2, was used to determine Sauter mean diameters for water sprays atomized by the injectors. The optical system shown in figure 2 consisted of a 1-milliwatt helium-neon laser, a 0.003-centimeter-diameter aperture, a 7.5-centimeter-diameter collimating lens, a 10-centimeter-diameter converging lens, a 5-centimeter-diameter collecting lens, a scanning disc with a 0.05×0.05 -centimeter slit, a timing light and a photomultiplier detector. A complete description of the scanning radiometer and the method of determining mean particle diameters are given in reference 4.

CALIBRATION TESTS

The scanning radiometer was calibrated with two different water suspensions of uniformly sized latex particles having diameters of 25.7 and 45.4 micrometers, respectively. Dynamic calibration tests were made using vaporizing sprays formed by the breakup of single jets of water injected transversely into high velocity airstreams. One of the multiple orifice spray bars used to produce single water jets is shown in figure 3. A plot of Sauter mean diameter, D_{32} , against airstream velocity, obtained for the 0.040-inch diameter orifice and the 0.013-inch-diameter orifice spray, respectively, is shown in figure 4. Good agreement was obtained with the volume number mean diameter, D_{30} , determined experimentally in reference 1 and plotted in figure 4. The relationship between the Sauter mean and volume number mean diameters is given as $D_{32} = 1.29 D_{30}$ in reference 5, as determined by the Nukiyama-Tanasawa expressions for mean drop diameters.

TEST INJECTORS

The pressure atomizing and air atomizing fuel injectors used in this investigation are shown in figure 5. Physical characteristics of the injectors are given in Table I. Three pressure atomizing nozzles were tested having flow numbers of 0.300, 0.184, and 0.092 (liters/hr)/(N/m²)^{1/2}, respectively, at a water flow rate of 90.8 liters per hour.

Three variations of air atomizing injectors were tested; namely, the air assist, splash groove, and splash cone air atomizing nozzles. The air assist nozzle was tested both with and without a sonic cup attached to the tip of the nozzle, to determine the effect of the sonic cup on the fineness of atomization. The splash groove and splash cone nozzles had been used in previous combustor studies.

RESULTS AND DISCUSSIONS

Mean drop diameters were determined for water sprays using two different types of fuel injectors and the scanning radiometer. The two types of fuel injectors consisted of conventional pressure atomizing nozzles, improved air atomizing nozzles previously tested in experimental combustors, and an air assist nozzle operated with and without a sonic cup attached to the nozzle tip.

The first type of injector tested consisted of three pressure atomizing nozzles having flow numbers of 0.092, 0.184, and 0.300, respectively. The effect of airstream velocity and flow number on the Sauter mean diameter, D_{32} , obtained with the three pressure atomizing nozzles are shown in figure 6. Sauter and mean diameter decreased markedly when airstream velocity was increased and flow number was decreased. Over an airstream velocity range of 23 to 38 meters per second, the following expression was obtained; $D_{32} \sim V^{-0.75}$. Also, the slope of the curve increased as airstream velocity was further increased. This could be due to increased turbulence due to the nozzle mount and possibly an increase in evaporation rate of the spray.

The effect of flow number, FN, on D_{32} is shown in figure 7. Over a flow number range of 0.092 to 0.300 the following expression was obtained; $D_{32} \sim (FN)^{0.4}$. This expression agrees fairly well with the relationship $D_{32} \sim (FN)^{0.34}$ which was obtained in reference 6, using kerosene and a somewhat lower range of flow numbers (0.0182 to 0.0364).

The second type of injector tested, namely the air atomizing fuel injector, consisted of a splash groove nozzle, a splash cone nozzle, and an air assist nozzle. The effect of airstream velocity on the Sauter mean diameters obtained with the splash groove and splash cone nozzles is shown in figure 8. Both nozzles gave the following relationship: $D_{32} \sim V^{-0.75}$ over an airstream velocity range of 23 to 38 meters per second. As airstream velocity was further increased the slope of the curve increased. Finer atomization was obtained with the splash groove design due to the smaller orifices (0.051-centimeter-diameter) as compared with the splash cone design having 0.157-centimeter-diameter orifices. However, as shown in figure 9 the splash cone design had a value of D_{32} closer to that of transverse liquid jet breakup, than the splash groove design. This was attributed to the fact that the angle of liquid injection for the splash cone nozzle was 90 degrees as compared to 45 degrees for the splash groove nozzle.

The effect of airstream velocity on D_{32} for the air assist nozzle is shown in figure 10. A marked

improvement in fineness of atomization was obtained by attaching a sonic cup to the tip of the nozzle. The sonic cup gave a reduction in D_{32} of approximately 40 percent. The effect of airstream velocity on D_{32} was as follows: $D_{32} \sim V^{-0.75}$ with the conventional air assist nozzle and $D_{32} \sim V^{-0.6}$ with the sonic cup attached to the tip of the nozzle, over an airstream velocity range of 23 to 38 meters per second. The effect of airstream velocity on D_{32} was even greater at higher airstream velocities.

SUMMARY OF RESULTS

At water flow rates of 90.8 liters per hour, Sauter mean diameter decreased with increasing airstream velocity as follows; $D_{32} \sim V^{-0.75}$ for all of the nozzles tested, with the exception of the sonic air assist nozzle, when airstream velocity was varied over a range of 23 to 38 meters per second. The most effective nozzle in producing fine sprays was the sonic air assist nozzle. With this nozzle, Sauter mean diameter decreased with increasing airstream velocity as follows; $D_{32} \sim V^{-0.6}$ over an airstream velocity range of 23 to 38 meters per second. Also, the sonic cup appeared to reduce values of D_{32} by approximately 40 percent. Whether the cup actually produced acoustic oscillations or simply acted as a splash plate to improve breakup was not investigated.

Air atomizing nozzles used in previous combustor studies (splash cone and splash groove nozzles) appeared to follow the same general relationship of Sauter mean diameter decreasing with increasing airstream velocity as follows; $D_{32} \sim V^{-0.75}$ which was previously determined for the breakup of single transverse liquid jets (ref. 1). The maximum effectiveness of this type of breakup was obtained with the liquid injected normal to the airstream.

With pressure atomizing nozzles, the Sauter mean diameter decreased with increasing airstream velocity and decreasing flow numbers as follows; $D_{32} \sim (FN)^{0.4}$. Thus, flow number, as well as airstream velocity, appeared to be very important factors in determining the fineness of atomization for pressure atomizing nozzles.

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TABLE I. - FUEL INJECTOR CHARACTERISTICS

Injector	Orifice diameter, cm	Water pressure drop, N/m^2 *	Flow number, $(\text{liter/hr})/(\text{N/m}^2)^{1/2}$
Spray bar			
13 orifices	0.102	2.21×10^4	0.611
109 orifices	.033	2.96	.527
Pressure atomizing			
High flowrate	.340	9.17	.300
Medium flowrate	.280	24.48	.184
Low flowrate	.230	97.22	.092
Air atomizing			
Splash cone			
4 orifices	.157	3.72	.471
Splash groove			
42 orifices	.051	10.41	.281
Air assist			
Conventional			
** 13.8×10^4 , N/m^2 ^a	.500	3.45	.489
Sonic cup			
** 13.8×10^4 , N/m^2 ^a	.500	3.45	.489
** 41.4×10^4 , N/m^2 ^b	.500	5.38	.392

* Measured at a water flowrate of 90.8 liters per hour.

** Pressure drop and flowrate of the assist air.

^a 20 SCFM.

^b 35 SCFM.

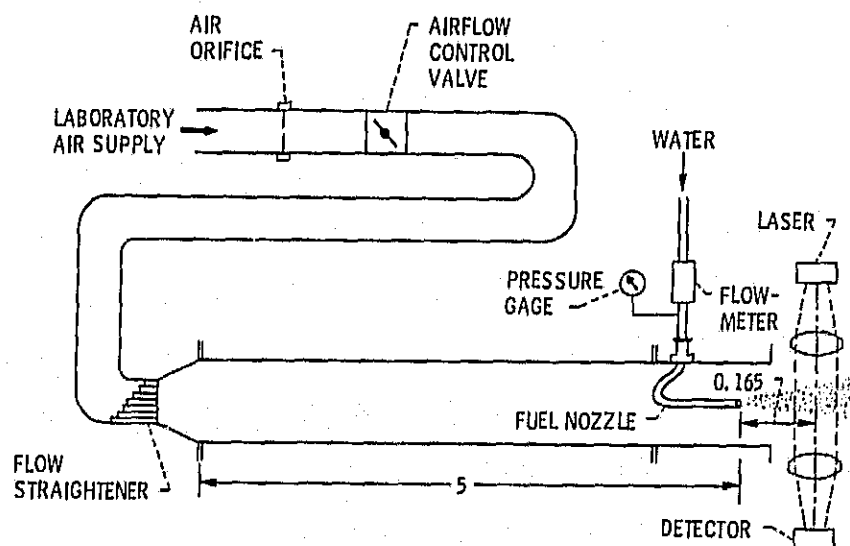


Fig. 1 Test facility and auxiliary equipment. (Dimensions are in meters.)

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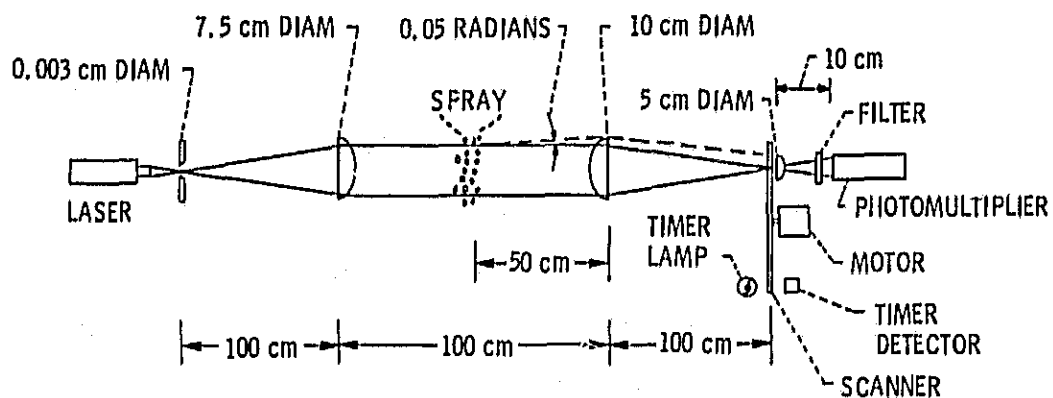


Fig. 2 Scanning radiometer optical path.

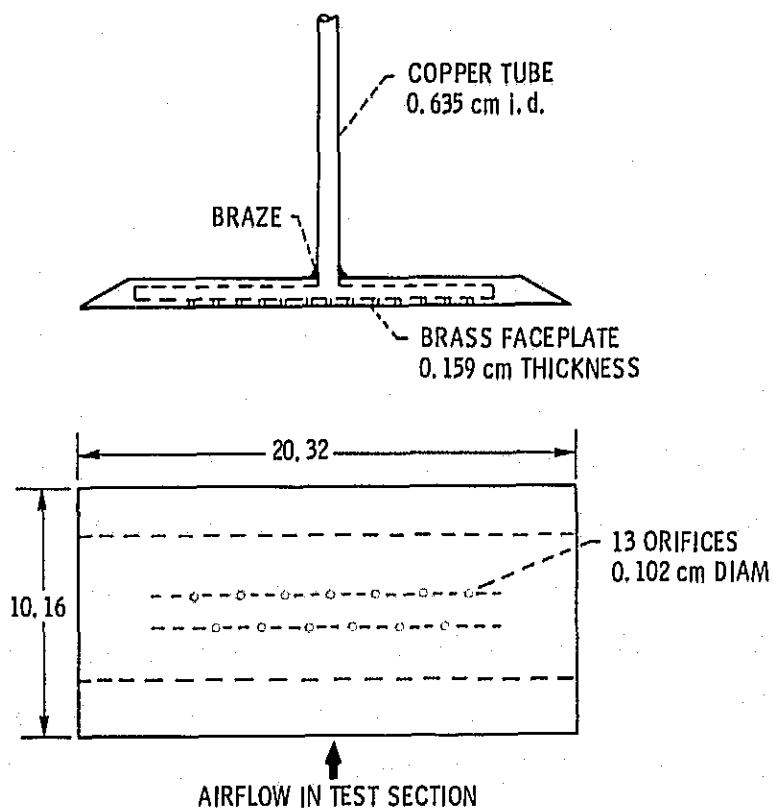
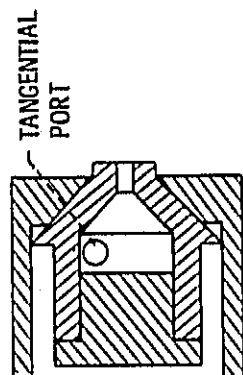
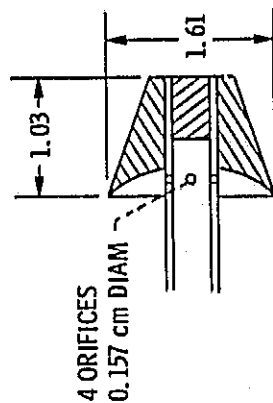


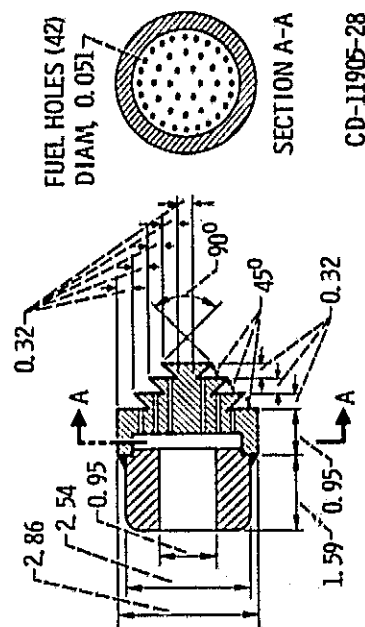
Fig. 3 Schematic diagram of multiple-orifice spray-bar. (Dimensions are in centimeters.)



(a) SIMPLEX PRESSURE-ATOMIZING NOZZLE.



(b) SPLASH-CONE AIR-ATOMIZING NOZZLE.



(c) SPLASH-GROOVE AIR-ATOMIZING NOZZLE.

Fig. 5 Schematic diagram of test injectors. (Dimensions are in centimeters.)

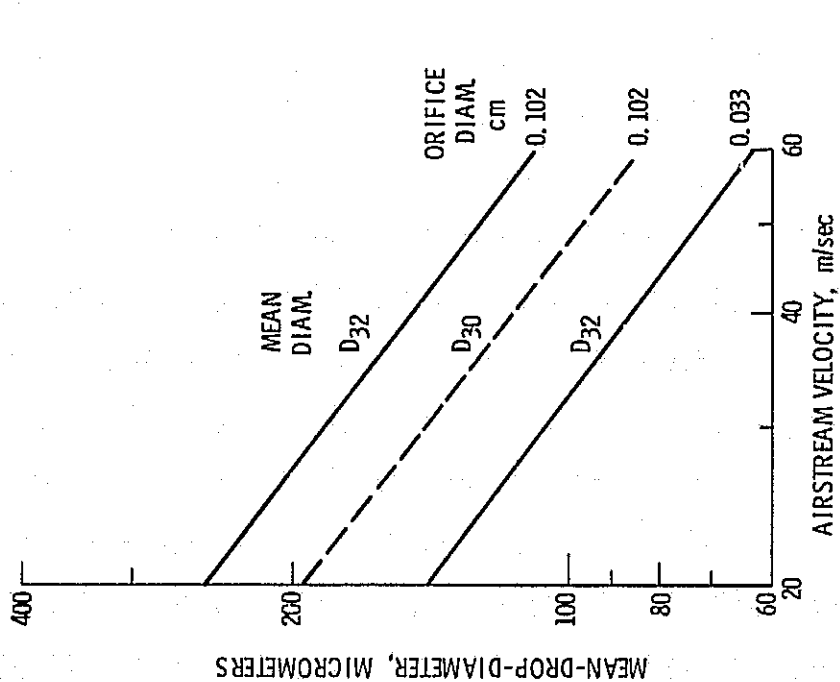


Fig. 4 Variation of mean-drop-diameter with airstream velocity for multiple-orifice sprayers.

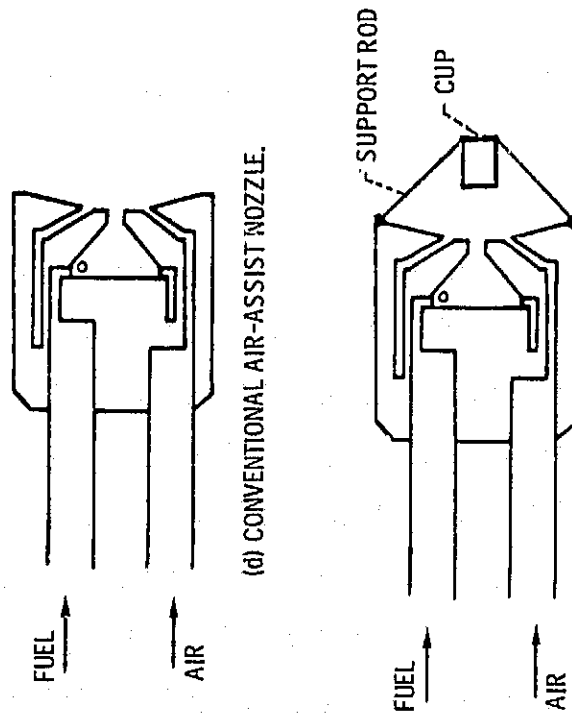


Fig. 5 Concluded.

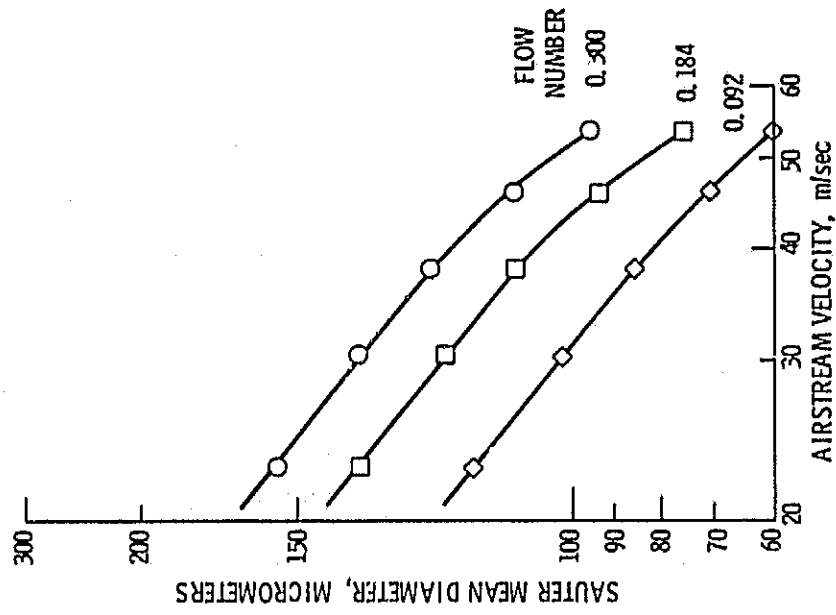


Fig. 6 Variation of Sauter mean diameter with air-stream velocity for pressure-atomizing nozzles.

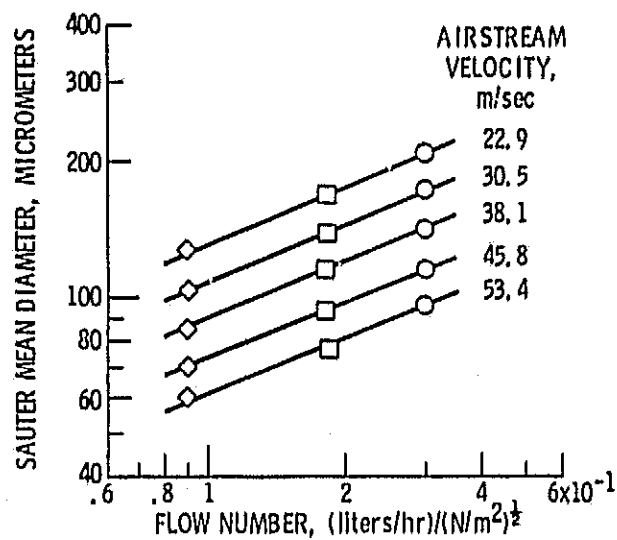


Fig. 7 Variation of Sauter mean diameter with flow number for pressure-atomizing nozzles.

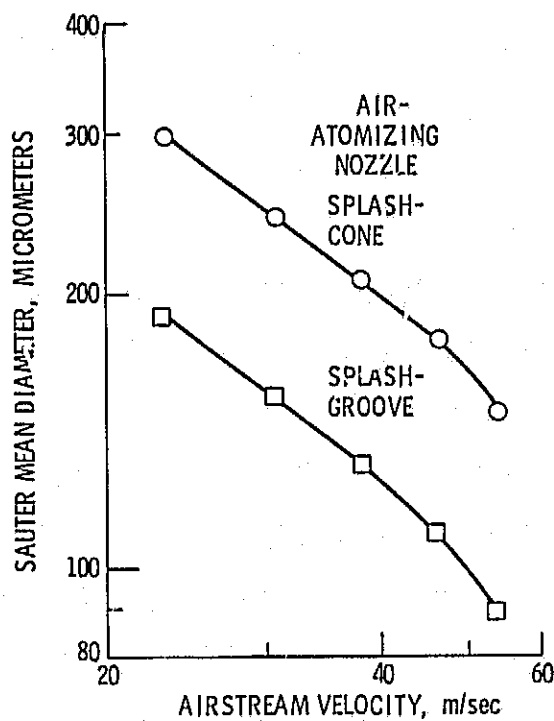


Fig. 8 Variation of Sauter mean diameter with airstream velocity for splash-groove and splash-cone air-atomizing nozzles.

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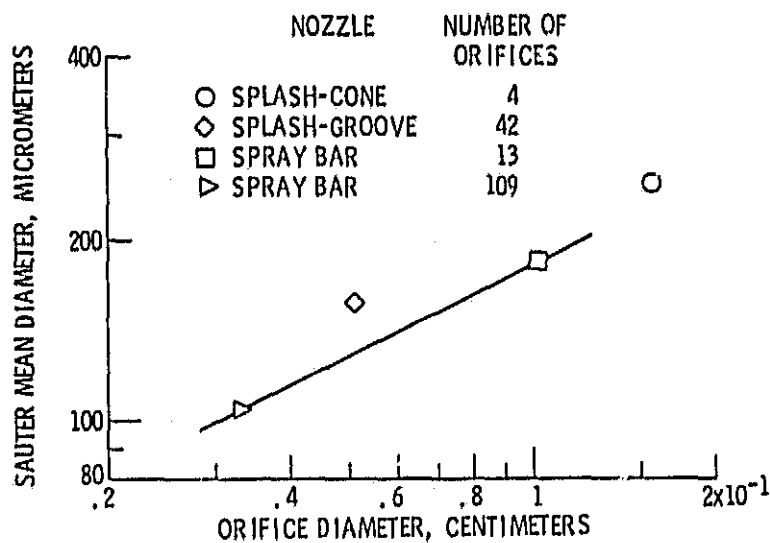


Fig. 9 Variation of Sauter mean diameter with orifice diameter for splash-groove and splash-cone nozzles at an air-stream velocity of 30.5 m/sec.

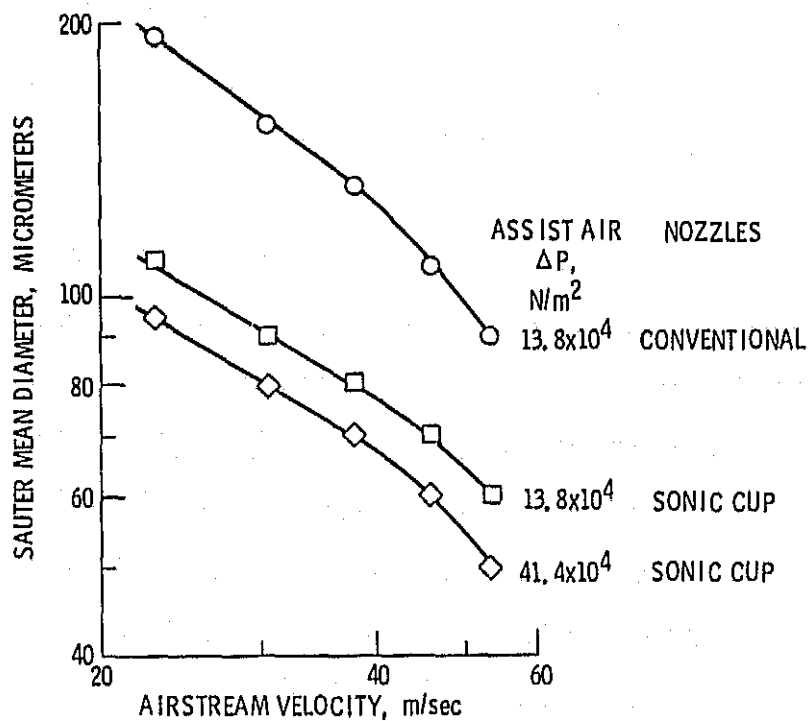


Fig. 10 Variation of Sauter mean diameter with airstream velocity for conventional and sonic air-assist nozzles.